

A triple-GEM telescope for the TOTEM experiment

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The TOTEM experiment at LHC has chosen the triple Gas Electron Multiplier (GEM) technology for its T2 telescope which will provide charged track reconstruction in the rapidity range $5.3 < |\eta| < 6.5$ and a fully inclusive trigger for diffractive events. GEMs are gas-filled detectors that have the advantageous decoupling of the charge amplification structure from the charge collection and readout structure. Furthermore, they combine good spatial resolution with very high rate capability and a good resistance to radiation. Results from a detailed T2 GEM simulation and from laboratory tests on a final design detector performed at CERN are presented.

1. INTRODUCTION

The TOTEM [1] experiment at the LHC collider will measure the total pp cross section with a precision of about $1 \div 2\%$, the elastic pp cross section over a wide range in $-t$, up to 10 GeV^2 , and will study diffractive dissociation processes. Relying on the “luminosity independent method” the evaluation of the total cross section with such a small error will require simultaneous measurements of the pp elastic scattering cross section $d\sigma/dt$ down to $-t \sim 10^{-3} \text{ GeV}^2$ (to be extrapolated to $t = 0$) as well as of the pp inelastic interaction rate with a good rapidity coverage up to the very forward region. Roman Pots (RP) stations at 147 m and at 220 m on both sides from the Interaction Point (IP), equipped with “edgeless planar silicon” detectors, will provide the former measurement. The latter will be achieved by two inelastic telescopes, T1 and T2, placed in the forward region of the CMS experiment on both sides of the IP. T1, using “Cathode Strip Chambers”, will cover the rapidity range $3.1 < |\eta| < 4.7$ while T2, based on “Triple-GEM” technology, will extend charged track reconstruction to the rapidity range $5.3 < |\eta| < 6.5$. These detectors will also allow common CMS/TOTEM diffractive studies

with an unprecedented coverage in rapidity. The T2 telescope will be placed 13.56 m away from IP and the GEMs employed will have an almost semicircular shape, with an inner radius matching the beam pipe. Each arm of T2 will have a set of 20 triple-GEM detectors combined into 10 aligned semi-planes mounted on each side of the vacuum pipe (Figure 1).

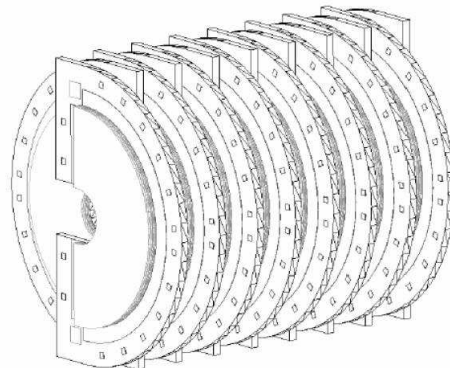


Figure 1. One arm of TOTEM T2 Telescope.

2. GEM TECHNOLOGY

The CERN developed GEM technology [2] has already been successfully adopted in other experiments such as COMPASS and LHCb and

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has been considered for the design of TOTEM very forward T2 telescopes thanks to its characteristics: large active areas, good position and timing resolution, excellent rate capability and radiation hardness. Furthermore, GEM detectors are also characterized by the advantageous decoupling of the charge amplification structure from the charge collection and readout structure which allows an easy implementation of the design for a given apparatus. The T2 GEMs use the same baseline design as the one adopted in COMPASS [3]: each GEM foil consists of thin copper clad polymer foil of $50\mu\text{m}$, with copper layers of $5\mu\text{m}$ on both sides, chemically perforated with a large number of holes of $70\mu\text{m}$ in diameter. A potential difference around 500 V applied between the two copper electrodes generates an electric field of about 100 kV/cm in the holes which therefore can act as multiplication channels (gains of order $10 \div 10^2$) for electrons created in a gas (Ar/CO₂ (70/30 %) for T2) by an ionizing particle. The triple-GEM structure, realized by separating three foils by thin ($2 \div 3\text{ mm}$) insulator spacers, is adopted in order to reduce sparking probabilities while reaching high total gas gains, of order $10^4 \div 10^5$, in safe conditions. The read-out boards will have two separate layers with different patterns: one with 256x2 concentric circular strips, $80\mu\text{m}$ wide and with a pitch of $400\mu\text{m}$, allowing track radial reconstruction with σ_R down to $70\mu\text{m}$, and the other with a matrix of 24x65 pads of 2×2 to $7 \times 7\text{ mm}^2$ in size from inner to outer circle, providing level-1 trigger information as well as track azimuthal reconstruction.

3. T2 TRIPLE-GEM SIMULATION

A detailed simulation of T2 triple-GEM detector has been developed starting from the existing implementation for the GEMs used at LHCb [4]. The general framework is relying on several packages allowing a complete and detailed “step by step” simulation, for a given gas mixture and detector geometry, for the several underlying processes: starting from the primary ionization up to the spatial and timing properties of the collected signals. The main framework is implemented in *Garfield*; the electric field mapping is

simulated with *Maxwell*; the electron/ion drift velocity and diffusion coefficients are evaluated with *Magboltz*; Townsend and attachment coefficients are simulated by *Imonte*; the energy loss by a given ionizing particle in gas and the cluster production process are evaluated by *Heed*. As an example, Figure 2 reports the simulation for the “weighting field” $\vec{E}_K^W(x)$ (defined by putting at 1 V the given readout electrode while keeping all the others at 0 V) for a pad electrode. Signal induction is then derived via the Ramo theorem: $I_k = -q\vec{v}(x) \times \vec{E}_K^W(x)$.

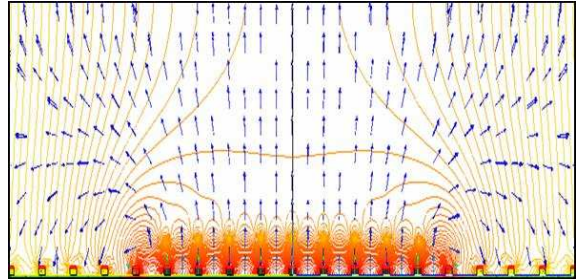


Figure 2. Simulation of the weighting field for a T2 GEM pad electrode.

From the reconstruction of the full process chain leading to signal collection, with proper modeling of lateral electron cluster diffusion through each GEM foil, the expected signal for a MIP particle has been derived for both strips and pads for typical values of the electric field in the drift and induction zones between GEM foils ($E_{d/t} \sim 3\text{ kV/cm}$). Timing properties, such as a typical signal time delay(duration) of $\sim 60(50)$ ns, have been found consistent with preliminary test beam studies on prototypes. Furthermore, the study of signals as a function of distance from electron cluster centroid, when combined with expected signal processing by the readout electronics, has shown a typical strip cluster size of $2 \div 3$ channels ($1 \div 2$ for pads), which is consistent with COMPASS test beam results [3]. Ongoing test beam activities, performed with final production detectors read by final design electronics (digital readout via VFAT chip), are expected to allow an improved test and tuning of current simulation.

4. TEST ACTIVITIES AT CERN

Two final full size detectors, whose components were provided by CERN, have been assembled by an Italian private company [5], and then tested at CERN Gas Detector Development Laboratory with a Cu X-Ray source ($K_{\alpha/\beta} = 8/8.9$ KeV). These activities involved studies on: general functionality, absolute gain, strip/pad charge sharing, energy resolution, time stability and response uniformity. In particular, the analysis of signals simultaneously collected from 8 strip/pad electrodes allowed to check the most important detector parameters. Figure 3 shows the total effective gain G_T ² for both strip and pad readout channels as a function of the applied HV: an expected gain of $8 \div 10 \times 10^3$ for a typical HV value of -4 kV is observed.

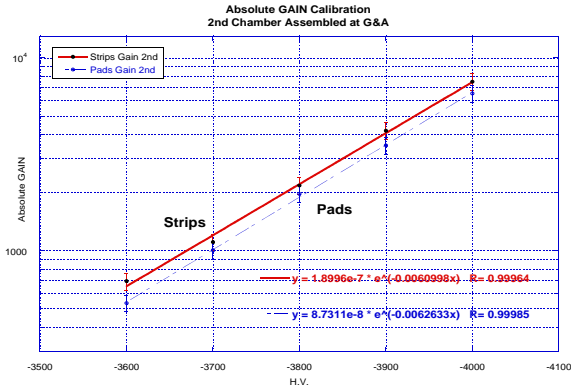


Figure 3. Strip/Pad gain as a function of the applied high voltage.

The study of strip/pad cluster charge sharing showed the expected correlation between the two clusters (Figure 4). A slightly higher charge collected by strips (about 10÷15%), considering the typical higher strip cluster size, is consistent with the design for an optimal setup of the common readout chip.

The evaluation of energy resolution represents another important detector test as it is related to the quality and uniformity of GEM foils. In fact, a not uniform gain over the irradiated zone will

² This parameter can be derived according to equation $G_T = I_{tot}/(e \cdot n \cdot f)$, from total readout current (I_{tot}) and X-Ray interaction rate (f) measurements, knowing the average number of electrons produced by an interacting X-Ray (n).

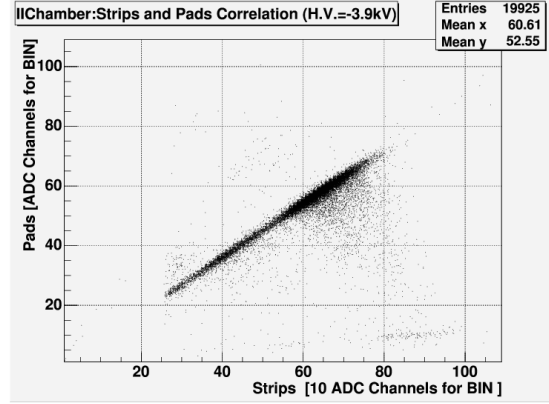


Figure 4. Strip/Pad cluster charge sharing. The reduced correlation at higher current values (around the 8 KeV peak) is attributed to not complete alignment of X-Ray beam to the instrumented readout channels.

results in an anomalous broadening of the peak in the response spectrum. An energy resolution of $\sim 20\%$, in terms of FWHM for the leading 8 KeV peak, was found to be well in agreement with the expected design performance of the detector.

Furthermore, time stability of signal has been tested with continuous detector irradiation over more than one hour and response uniformity checked by randomly moving the X-Ray source over the detector surface.

In conclusion detector performances well within expectations have been observed. A more extensive test on ten production detectors will be performed at the incoming test beam activities.

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